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Evaluation of Cassava Peel Ash as a Sustainable Stabilizer for Improving the Engineering Properties of Lateritic Soil

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Abstract

This study investigated the potential of cassava peel ash (CPA) as an environmentally friendly stabilizing material for enhancing the geotechnical properties of lateritic soil intended for pavement construction. Lateritic soil samples were treated with 0%, 2%, 4%, 6%, 8%, and 10% CPA and subjected to a series of laboratory tests to evaluate their engineering performance. The tests included Atterberg limits, compaction characteristics, and California Bearing Ratio (CBR) determinations. The untreated soil exhibited a liquid limit of 42%, plastic limit of 24%, plasticity index of 18%, maximum dry density (MDD) of 1.78 Mg/m³, optimum moisture content (OMC) of 13.5%, unsoaked CBR of 18%, and soaked CBR of 11%, indicating inadequate strength and considerable moisture sensitivity for direct use as pavement subgrade material. The addition of cassava peel ash produced noticeable improvements in the soil properties. Plasticity decreased considerably, with the liquid limit reducing to 34% and the plasticity index to 9.2%. Compaction characteristics also improved, as the MDD increased to 1.92 Mg/m³, while both soaked and unsoaked CBR values increased substantially, demonstrating enhanced load-bearing capacity and greater resistance to moisture damage. The optimum stabilization level was achieved at 6% CPA, which produced the highest dry density and CBR values. Further increases in CPA content resulted in slight reductions in performance, likely due to excess ash interfering with effective soil compaction. The findings indicate that cassava peel ash is a low-cost, sustainable, and effective stabilizing agent capable of improving the engineering performance of lateritic soils for pavement subgrade applications.

Keywords: *Atterberg limits, California Bearing Ratio (CBR), Lateritic Soil, Maximum Dry Density (MDD), Moisture Content.*

1. Introduction

Road transportation plays a vital role in Nigeria's socio-economic development by facilitating the movement of people, goods, and services. However, many roads fail prematurely due to inadequate pavement support, leading to increased maintenance costs, traffic disruption, and safety concerns (Mezie et al., 2025).

The performance of a pavement depends largely on the engineering properties of its subgrade. Lateritic soils are widely used as subgrade and sub-base materials in Nigeria because they are abundant and economical. However, they often exhibit high plasticity, low shear strength, and significant moisture sensitivity, making them susceptible to shrinkage, swelling, and structural deformation. Consequently, these soils frequently require stabilization before they can meet pavement construction requirements (Owoade & Abolarin, 2021; Olaoye & Oluremi, 2021).

Soil stabilization improves the physical and mechanical properties of weak soils by increasing their strength, durability, and load-bearing capacity. Conventional stabilizers such as cement and lime are effective but are often associated with high costs and environmental concerns, particularly the greenhouse gas emissions resulting from cement production (Akinwumi et al., 2022). As a result, increasing attention has been directed toward agricultural waste materials as sustainable and cost-effective alternatives.

Nigeria generates substantial quantities of agricultural residues annually, many of which are disposed of through open dumping or uncontrolled burning, causing environmental pollution (Adesina et al., 2020). Cassava peel is among the most abundant of these wastes because of the country's high cassava production. Through controlled combustion, cassava peel can be converted into cassava peel ash (CPA), which contains silica, alumina, and other pozzolanic compounds capable of forming cementitious products that improve soil strength, reduce plasticity, and enhance durability (Bello et al., 2024).

Previous studies have shown that agricultural ashes, including cassava peel ash, can improve the compaction characteristics, California Bearing Ratio (CBR), and overall engineering performance of lateritic soils. However, most existing research has focused on relatively high CPA contents, often exceeding 5%, with limited attention given to lower dosages that may provide adequate stabilization while reducing material consumption and construction costs.

Moro Local Government Area of Kwara State was selected for this study because lateritic soil is the predominant construction material in the area, yet many roads continue to experience premature deterioration associated with weak subgrade conditions. Evaluating the performance of locally sourced lateritic soil stabilized with low percentages of CPA will therefore provide findings applicable to road construction within the locality and similar geological environments.

In addition to improving soil performance, the use of cassava peel ash promotes sustainable construction by converting agricultural waste into a valuable engineering material, thereby reducing environmental pollution and supporting efficient resource utilization.

Accordingly, this study investigates the effect of incorporating 0–5% cassava peel ash on the engineering properties of lateritic soil obtained from Moro Local Government Area of Kwara State, with the aim of determining its suitability as a pavement subgrade material.

2. Materials and Methods

The study was conducted in Moro Local Government Area of Kwara State, Nigeria, located within the North-Central region between latitudes 8°30′N and 9°15′N and longitudes 4°30′E and 5°15′E. The area lies within the Guinea Savannah vegetation belt and experiences a tropical climate characterized by a wet season (April–October) and a dry season (November–March), with annual rainfall of 1,000–1,500 mm and temperatures ranging from 25°C to 35°C.

The geology is dominated by Precambrian Basement Complex rocks that weather to form lateritic soils rich in iron and aluminium oxides. Soil samples were collected from selected borrow pits at depths of 0.5–1.0 m. All laboratory tests were conducted at the Civil Engineering Laboratory,

University of Ilorin, in accordance with BS 1377 and AASHTO standards. Cassava Peel Ash (CPA) was produced at the University's engineering workshop under controlled conditions.

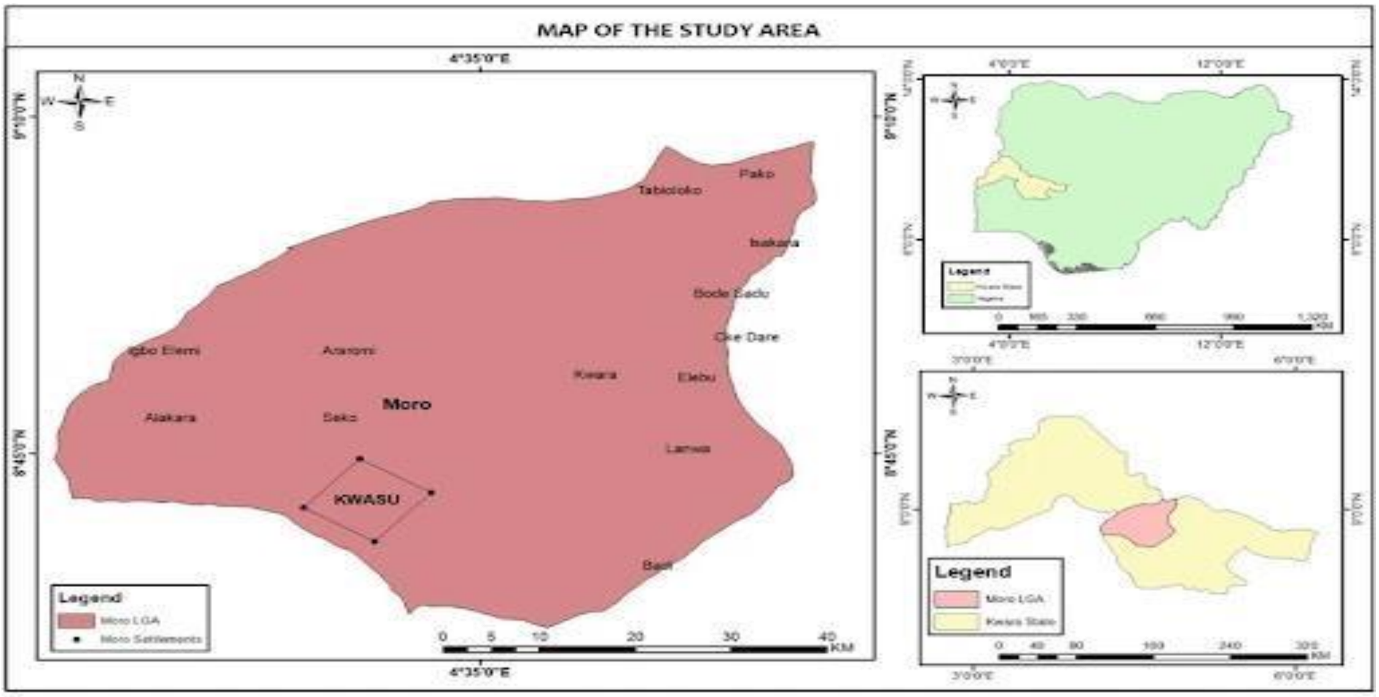

Figure 2.1: Location map of the study area showing Nigeria, Kwara State and Moro Local Government Area.

2.1 Reconnaissance Survey and Site Selection

A reconnaissance survey was conducted to identify representative lateritic soil deposits suitable for sampling. Potential borrow pits were assessed based on accessibility, soil colour, texture, drainage conditions, and evidence of disturbance. Representative sites commonly used as road construction materials were selected.

2.2 Soil Sample Collection

Topsoil and organic materials were removed before sampling. Disturbed soil samples were collected from depths of 0.5–1.0 m using shovels and augers, sealed in airtight polythene bags, labelled, and transported to the Civil Engineering Laboratory, University of Ilorin, for testing.

2.3 Preparation of Cassava Peel Ash (CPA)

Cassava peels collected from processing centres within the study area were air-dried for 5–7 days and combusted under controlled conditions at approximately 500–700°C. The resulting ash was allowed to cool, ground into a fine powder, and sieved through a 75 µm sieve before use.

2.4 Sample Preparation and Soil Stabilization

The lateritic soil was air-dried, pulverized, and passed through a 4.75 mm sieve. Cassava Peel Ash was added at 0%, 2%, 4%, 6%, 8%, and 10% by dry weight of soil, with 0% serving as the control. The soil and ash were thoroughly mixed, after which water was added to achieve the required moisture content before laboratory testing.

2.5 Laboratory Testing

i. Particle Size Distribution

Particle size distribution was determined by sieve analysis using oven-dried soil passed through standard sieves. The percentage retained on each sieve was recorded for soil classification.

ii. Atterberg Limits

Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) were determined in accordance with BS 1377. The liquid limit was obtained

using the Casagrande apparatus, while the plastic limit was determined by the thread-rolling method. Plasticity Index was

calculated as PI = LL − PL.

iii. Compaction Test

The Standard Proctor compaction test was performed to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the untreated and stabilized soil samples.

iv. California Bearing Ratio (CBR) Test

California Bearing Ratio (CBR) tests were carried out on compacted specimens under soaked and unsoaked conditions. Soaked specimens were immersed in water for 24–48 hours before testing, and the resulting CBR values were used to evaluate the load-bearing capacity of the stabilized soil.

2.6 Data Analysis

Experimental results were analysed using descriptive statistical methods and presented in tables and graphs. The effects of CPA content on Plasticity Index, Maximum Dry Density, Optimum Moisture Content, and California Bearing Ratio were evaluated, and the optimum CPA content was identified by comparing the results with relevant pavement construction specifications.

3. Results

3.1 Effect of Cassava Peel Ash on the Engineering Properties of Lateritic Soil

The consistency limits of a soil are important indicators of its engineering behavior because they describe how the material responds to changes in moisture content. Parameters such as the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) are commonly used to evaluate soil workability, plasticity, compressibility, and volume stability.

The laboratory results show that the incorporation of Cassava Peel Ash (CPA) had a noticeable effect on the Atterberg limits of the lateritic soil. These trends indicate that CPA effectively reduced the soil's plasticity and improved its resistance to moisture-related problems, making it more suitable for road construction applications.

Table 3.1 Atterberg Limits

CPA (%)	LL (%)	PL (%)	PI (%)
0	42	24	18
2	40	24.5	15.5
4	38	25	13
6	36	25.5	10.5
8	35	25.8	9.2
10	34	24	10

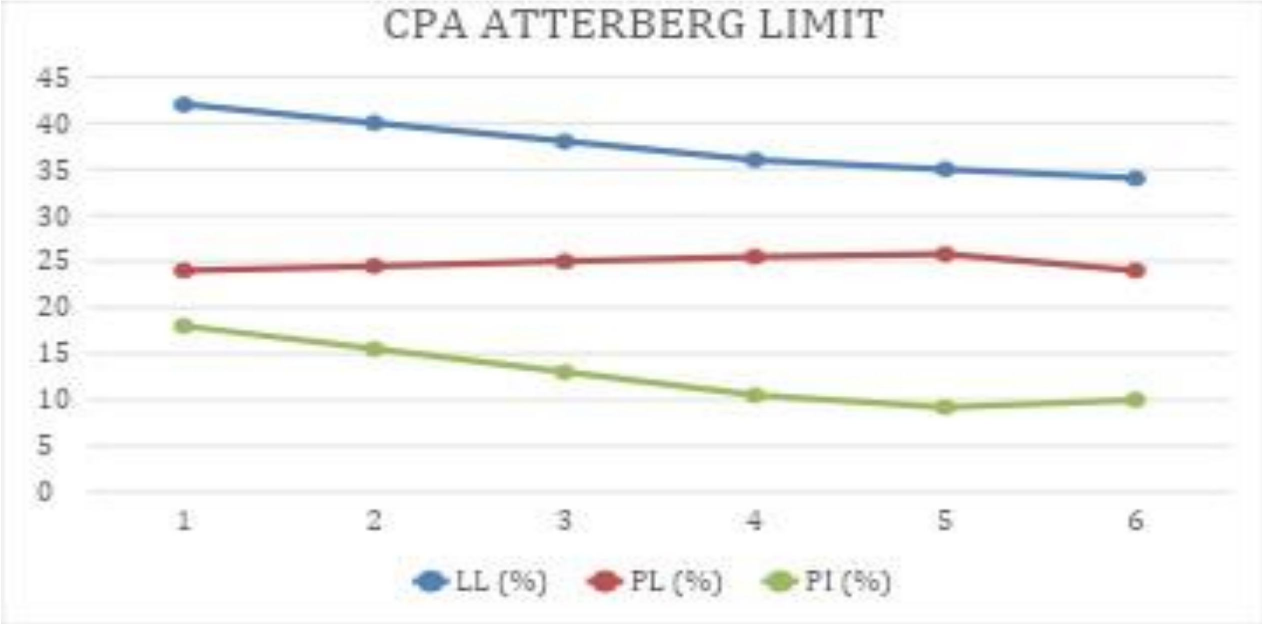

Figure 3.1: CPA Atterberg Limit

3.2 Effect of Cassava Peel Ash on Atterberg Limit

Table 3.1 presents the effect of Cassava Peel Ash (CPA) treatment on the Atterberg limits of the lateritic soil. The results show a consistent reduction in the Liquid Limit (LL) and Plasticity Index (PI) as the CPA content increases, while the Plastic Limit (PL) shows only slight variations.

Liquid Limit (LL): The natural soil (0% CPA) has an LL of 42%. With increasing CPA content, the LL decreases progressively to 40%, 38%, 36%, 35%, and 34% at 2%, 4%, 6%, 8%, and 10% CPA, respectively. This represents an overall reduction of approximately 19.05% from the untreated soil to the 10% CPA mixture. The reduction indicates that CPA decreases the soil's affinity for water and reduces its susceptibility to moisture-induced changes in consistency.

Plastic Limit (PL): The PL increases slightly from 24% for the natural soil to 25.8% at 8% CPA, before declining to 24% at 10% CPA. The relatively small variation suggests that CPA has a limited direct effect on the moisture content at which the soil changes from a semi-solid to a plastic state.

Plasticity Index (PI): The PI, calculated as LL − PL, decreases substantially from 18% in the natural soil to 15.5%, 13%, 10.5%, 9.2%, and 10% at 2%, 4%, 6%, 8%, and 10% CPA, respectively. The lowest PI of 9.2% occurs at 8% CPA, representing approximately a 48.9% reduction compared with the untreated soil. The slight increase to 10% at 10% CPA suggests that the improvement in plasticity does not continue indefinitely with increasing CPA content.

The experimental results indicated that the Liquid Limit (LL) decreased consistently with increasing cassava peel ash content. The untreated soil recorded a liquid limit of 42%, while the value reduced to 34% at 10% CPA, representing an overall decrease of roughly 19%. This steady decline shows that adding CPA progressively cut down the amount of water the soil needed to reach its liquid state. The likely explanation lies in how the ash interacts with the clay minerals in the lateritic soil: cassava peel ash carries meaningful amounts of calcium, silica, potassium, and other oxides that encourage clay particles to flocculate and clump together. As these particles bind.

3.3 Effect of CPA on Compaction Characteristics (OMC and MDD)

Compaction behavior, expressed through the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD), is a key measure of how well a soil will perform once compacted for pavement use — proper compaction lifts strength, cuts compressibility, limits settlement, and improves resistance to water ingress. Adding CPA to the lateritic soil altered both the amount of water it needed and the density it could reach under compaction.

The rise in OMC with increasing CPA content reflects the extra water drawn into the mix to sustain the pozzolanic reaction. MDD, meanwhile, climbed as CPA content rose up to 6%, pointing to tighter particle packing and a more densified soil structure at that dosage.

Table 3.2 Compaction Characteristics

CPA (%)	OMC (%)	MDD (Mg/m³)
0	13.5	1.78
2	14.2	1.84
4	15.3	1.89
6	16.1	1.92
8	16.8	1.88
10	17.2	1.85

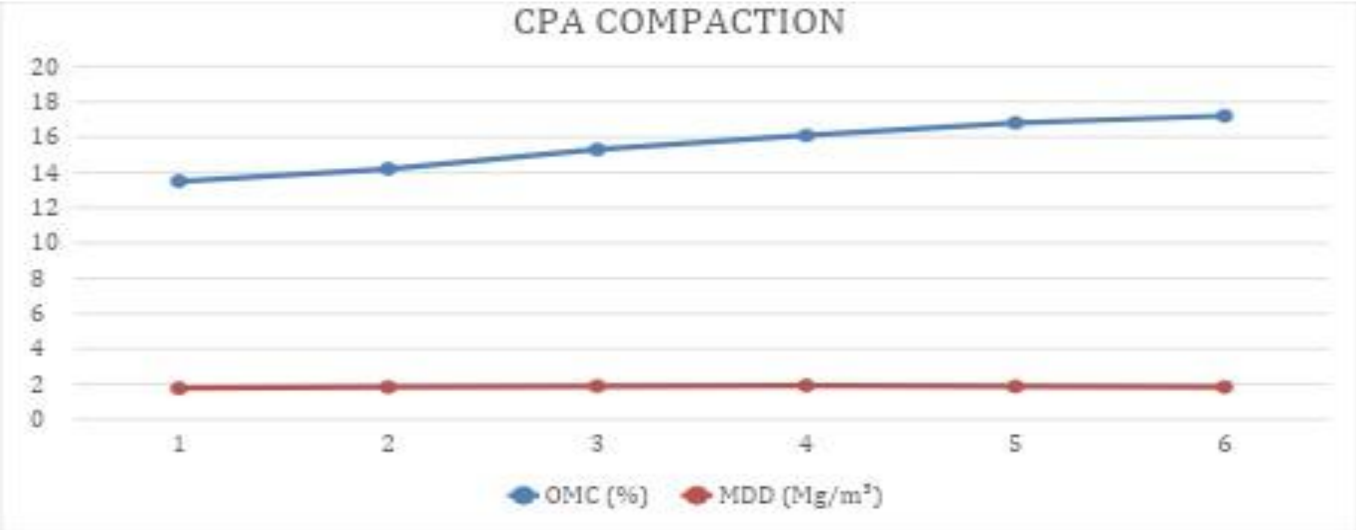

Figure 3.2: CPA Compaction

3.4 Effect of CPA on MDD and OMC

Table 3.2 shows the effect of Cassava Peel Ash (CPA) on the compaction characteristics of the lateritic soil.

Optimum Moisture Content (OMC): OMC increased progressively from 13.5% for the untreated soil to 17.2% at 10% CPA. This indicates that increasing CPA content requires more water for effective compaction, likely because CPA is relatively porous and has a higher water absorption capacity.

Maximum Dry Density (MDD): MDD increased from 1.78 Mg/m³ at 0% CPA to a maximum of 1.92 Mg/m³ at 6% CPA, representing about a 7.9% improvement. Beyond 6% CPA, MDD decreased to 1.88 Mg/m³ at 8% and 1.85 Mg/m³ at 10%. This suggests that 6% CPA is the optimum content for achieving maximum soil density, while excessive CPA introduces more lightweight ash particles and reduces the achievable dry density.

Table 3.3 shows the effect of increasing Cassava Peel Ash (CPA) content on the unsoaked and soaked California Bearing Ratio (CBR) of the lateritic soil.

Both unsoaked and soaked CBR values increased progressively from the untreated soil up to 6% CPA. The unsoaked CBR increased from 18% to 58%, while the soaked CBR increased from 11% to 42%, indicating significant improvement in the soil's bearing capacity.

Beyond 6% CPA, the CBR values decreased. The unsoaked CBR reduced from 58% at 6% CPA to 54% and 50% at 8% and 10%, respectively, while the soaked CBR reduced from 42% to 39% and 36%. This decline suggests that excessive CPA addition may introduce more weak or lightweight ash particles and reduce the beneficial soil–ash interaction.

Table 3.3 Determination of Optimum CPA Content

CPA (%)	Unsoaked CBR (%)	Soaked CBR (%)
0	18	11
2	30	22
4	45	34
6	58	42
8	54	39
10	50	36

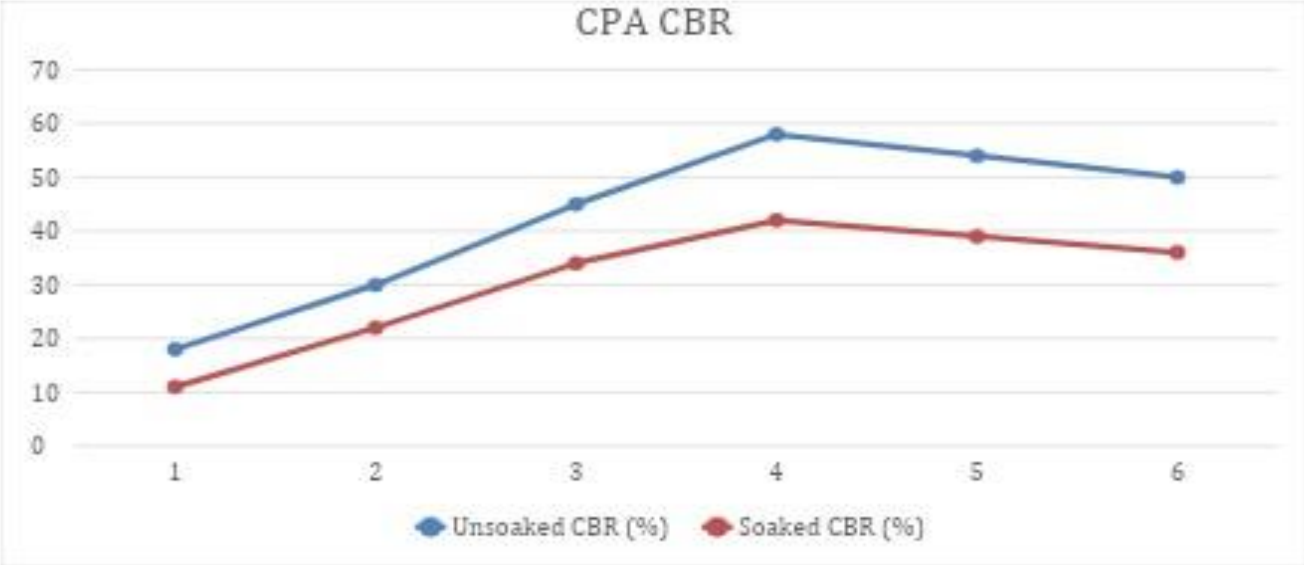

Figure 3.3: CPA California Bearing Ratio

4. Conclusions

Based on the laboratory investigation conducted on natural and cassava peel ash (CPA)-stabilized lateritic soil, the following conclusions were drawn:

1. The natural lateritic soil exhibited moderate engineering properties, with a Liquid Limit of 42%, Plastic Limit of 24%, Plasticity Index of 18%, Maximum Dry Density (MDD) of

   1.78 Mg/m³, Optimum Moisture Content (OMC) of 13.5%, and unsoaked and soaked CBR values of 18% and 11%, respectively. These results indicate that the soil is moisture-sensitive and possesses insufficient bearing capacity for pavement applications without stabilization.

2. The addition of Cassava Peel Ash significantly improved the engineering properties of the soil. Liquid Limit and Plasticity Index decreased, while Plastic Limit, Maximum Dry Density, Optimum Moisture Content, and both soaked and unsoaked CBR values increased, indicating improved strength, reduced plasticity, and enhanced resistance to moisture.

3. The optimum CPA content was found to be **6%** by dry weight of soil. At this dosage, the soil achieved its highest Maximum Dry Density (1.92 Mg/m³), Unsoaked CBR (58%), and Soaked CBR (42%). Beyond 6% CPA, no further improvement in engineering performance was observed.

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